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Abstract

Reviews current literature on computed tomography (CT). The operational procedures for CT machines are described and the contribution of this new radiological technique to the medical field is analysed. The operational jprinciple of a CT scanner and its clinical application are described. The use of the CT scanner and its clinical application are described. The use of the CT scanner in radiodiagnostics raises several problems in particudlar the effective clinical use of the CT in relation to the risk-benefit ratio associated with a tomographic examination. Doses received by patients during a typical tomographic examination are assessed.

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COMPUTERISED AXIAL TOMOGRAPHY (CAT)

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SUMMARY

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This paper is a review of current literature on computed
tomography (CT). It begins by describing the operational
procedures for CT machines, then analyses the contribution
of this new radiological technique to the medical field.
Finally, the risk-benefit ratio is considerable, particular
attention being paid to the dose received by the patient
during a typical tomographic examination.

Computerised Axial Tomography (CAT)

INDEX

Introduction

Tomography or stratigraphy is a radiodiagnostic method providing a radiographic representation of a single layer of the human body in parallel with its longitudinal axis. Unlike radiography, the result is, as far as possible, free of the superimposition of the images relative to the strata and underlying the required plane. Fig. 1 shows a diagram of the operational principle of this method which is based on the counter-rotation of the radiogenic tube and of the photoplate, the centre of rotation of which is situated at the same level of the anatomical stratum concerned.

While the anatomical structures placed on the plane which contains the centre of rotation are always projected at the same point of the film and produce fairly clearcut images, those on the other planes are projected on points that are always diverse, so that their images produce only a diffuse opacity [45, 46].

Transverse axial tomography is based on an analogous principle: this method provides images transverse to a plane perpendicular to the longitudinal axis of the human body (v. fig. 2).

In no case does the tomographic image have the sharp definition obtained by a normal radiographic examination which presents the advantage of showing a three-dimensional body in a bidimensional manner.

This involves the loss of a large quantity of available information. It is, on the other hand, very important that the method used for gathering the data ensures that full use is made of all the information associated with the passage of a beam of x-rays through a body and that this information is interpreted with the maximum efficiency.

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The new radiological technique known as Reconstructive Tomography or Computerised Tomography (CT) or Computerised Axial Tomography (CAT) is certainly capable of using this information and presenting the result in the form of much clearer and more sharply defined images.

Like the conventional Transverse Axial Tomography (transaxial tomography), Computerised Axial Tomography (CAT) provides, as the result, an image relative to an anatomical section perpendicular to the longitudinal axis of the human body (fig. 3). The difference between these two techniques is that in the CAT, the x-rays, once having crossed over the section examined, do not impress a photoplate but are picked up at different angles, by suitable detectors which transfer the information relating to the attenuation of the x-rays in passing through the fabric to a computer. The latter will be able to reconstruct the image of the section examined, forming a picture of the density values of the materials constituting the section itself, in the form of a matrix which is thus represented on a screen with various shades of gray (or colours) (v. photo 1 and 2).

The purpose of this work is to present the operational principles of Computerised Axial Tomography (which, in the following, we shall designate by CAT or CT) and to compare this technique with other traditional techniques (ungiography, scintigraphy etc.).

This analysis also represents a starting point for a dialogue with the health personnel interested in surveying, on a national level, the number of CT appliances and their location in relation to the effective health requirements of the country.

Furthermore, the problem of the CAT always involves the

correct assessment of the ratio of risk to benefit, which is one of the cardinal points in the protection of the patients from ionising radiations. It is said, on this subject, that the Istituto Superiore di Sanità (in agreement with CNEM) has for some time, instituted programmes (conventional determination of the genetically significant dose and NEXT programme) which proposes, as their purpose, the protection of the patient in a radiodiagnostic field.

And, with regard to the protection of the patient, in this respect an analysis will be made of the doses given to the patient in the course of an examination with the CAT.

1. HISTORY AND DEVELOPMENT OF THE COMPUTERISED AXIAL TOMOGRAPHY

1.1 Origin, development and marketing of the CAT

The origin of the CAT goes back to 1961 when Oldendorf[1] was the first to have the idea of passing a beam of x-rays, from different angles, through an object, for the purpose of measuring the absorption coefficients. Later, Cormack[2] discussed the possibility of measuring the transmission of x-rays along "lines parallel to a large number of different directions", so as to obtain a sequence of transmission profiles of the rays themselves.

These profiles, subjected to a Fourier analysis, were then used to reconstruct the linear absorption coefficients relative to the scanned area of the object examined. Cormack concluded that these results could be applied to medical radiology for determining the variability of the absorption coefficients of the x-rays, which are strictly correlated with the density of the various tissues and

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organs of the human body.

The methodology which had led to the development of computerised axial tomography was readily available.

A prototype (called EMI scanner), capable of obtaining images of the soft tissues of the skull and usable for medical studies, was designed by Hounsfield, in 1970, in the central research laboratories of EMI Limited, Haynes, Middlesex, England, after years of development[3].

The EMI scanner was introduced at the annual congress of the British Institute of Radiology in 1972, after 18 months. of clinical experimentation on the prototype.

The British, constructing an instrument that revolutionised medical and radiodiagnostic technology, was able to count on wide commercial possibilities, in the international market. In particular, EMI entered, very forcefully, the American market, always dominated by the industrial giants in the USA[4]. The American response to the British challenge was at once massive: many American firms, supported by advanced basic technology, entered the CT scanner market.

In February 1974 the first "whole body scanner" (a scanner for the whole body) was installed in the Georgetown University Medical Center; this scanner was designed by Ledley and constructed by Pfizer[5].

In November 1976, the manufacturer making CT scanners and exhibiting at the congress of the Radiological Society of North America, were[6] twelve in number: EMI, General Electric, Ohio Nuclear, Artronic, Varian, Siemens, Syntax, Searle, American Scientist and Engineering Pfizer to which were added, later, Philips and Parker.

Computerised axial tomography turned out, later, to be an increasingly important commercial as well as a scientific business[7], and it became a fundamental matter, for the manufacturing firms, to improve the appliances, seeking for avant-garde technical solutions with a view to remaining competitive in the commercial market.

EMI, which had originally counted on being the only firm selling CT units, subsequently increased its production in order to overtake its monthly quota of one appliance per month[4].

However, Ter-Pogassian points out[4] that, among the many companies that have successively entered the market in competition with EMI, there were, as well as the industrial giants and the firms already specialising in fields similar to radiological technology (nuclear medicine, therapeutic radiation etc.) there were also firms without any technical and scientific experience in the specific field, and that therefore were not sufficiently reliable and competent to deal with this type of product.

Another interesting aspect underlined be Ter-Pogossian, was the American citizens' extraordinary knowledge and awareness of the importance of tomography in medical diagnosis. From the discovery of x-rays to the present day, there was never a radiographic technique so publicised and discussed by the media. Television programmes, reviews, local daily papers showed, at least once, a section of the brain and of the abdomen obtained with the CAT.

At present there is a big demand for CT scanners; in fact, the new technique, as well as assisting, tends, in some cases, to act as a substitute for the conventional radiodiagnostic methods. In the USA alone in August '76,

more than 300 units were installed, compared with the 5 in December '73 and another hundred are already on order[6, 8]. According to a rough estimate[8] the number of CT scanners at present working in Italy is about 18 units installed, apart from those in the large cities such as Rome (5 units, 4 of which are in private clinics): Milan, Turin, Bologna, Florence, Genoa, Naples, Palermo, and in minor centres such as Ancona, Siena, Verona, Udine.

In USA, the acquisition and installation of a CT scanner cost in 1976, 350 to 700 thousand dollars, while in Italy the cost of this apparatus was around 660 million lira. Furthermore, the introduction in the market of the "total body scanners" caused hospitals that already had a brain scanner, to be interested in acquiring this new equipment.

Evens and Jost[10] provide data relating to 98 out of 140 CT installations in USA (80 head scanners and 198 total body scanners): among other things, they emphasise that a CT unit, works, on an average, for 5.4 days in the week and 11.8 hours in the day. The average number of patients examined is 58 per week.

The cost of an examination is, according to Evens and Jost[10], 120-130 dollars, while, according to Jurgen[8], it is about 200 dollars. And, according to Jurgen, considering an an average of 12 examinations per day per apparatus, it can be concluded that for 300 CT units in operation in USA in 1976, the annual turnover has been around 200 million dollars.

It should also be emphasised[11] that, in USA, the cost of a single examination done with the CAT is equal to the cost, per head, incurred in a year with the traditional radiological examinations.

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In Italy, the overall cost of a neurological CT examination, defined by the operators of the Servizio di Radiologia - Neuroradiologia dell'Ospedale Regionale Umberto I, Ancona[2], in 1976, was approximately 60 thousand lira. In 1976, this centre examined a total of 4;264 patients, with an average of 16.5 patients per day; given the possibility of examining a greater number of patients per year — for example, 6 thousand — the cost of a single examination could drop to 45 thousand lira. Also, the use of a CT in hospital involves a reduction in the number of pneumocephalographs, angiographs and scintigraphs with a consequent reduction in the stay in hospital and the recovery time[13]. At present, a tomographic examination in a private clinic involves the patient in a cost of about 200-400 thousand lira.

1.2   Team

A CT apparatus alone is installed in the radiological department of a hospital or of a private clinic and is assigned to a team containing a radiologist, neurologist or neurosurgeon[10].

Some details are necessary at this point: the inclusion of the computerised tomographic technique has undoubtedly emphasised the ever-increasing importance of the physico-mathematical sciences in medical disciplines. It is thus indispensable, even more so than in the past, to include physics in the hospital's competence and in the activities involved in immediate clinical applications.

Obviously, the development of the CT has been and will be, so rapid, that the possible technical preparation of the new radiologists will not be adequate: the difficulties can. be overcome by setting aside the separate individual aspects

and arranging a steady interdisciplinary training programme for the teams.

2. OPERATIONAL PRINCIPLE OF A CT SCANNER

2.1 Classification

In the continuous technological development of the CT, it is possible to define[0] three generations of apparatus:

1st Generation
A single beam of x-rays is applied and one or two detectors: the source-detector system rotates by 1° per scan.

To illustrate the functioning of this type of apparatus, let us consider the original CT scanner produced by EMI Ltd. for cerebral tomography. In the EMI scanner[2], the x-ray tube and two sparking detectors (sodium iodide crystals, NaI) are fixed and rotate around the head of the patient. This is encircled by water which acts as a balancing medium, in such a way that the x-rays pass across the same complex of water and tissue.

Initially, the source-detector system made one linear scan parallel and lateral to the object to be examined: at present, the detectors make 160 readings of the intensity of x-rays transmitted (v. fig. 4).

On completion of a linear scan, the system rotates by 1°, thus repeating with another linear scan.

When the scanning is complete (corresponding to a rotation of 180° completed in 4-5 minutes) it comprises 180 linear scans with a total number of readings of 28800 (180 x 160)

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(fig. 5).

The corresponding values, as they are recorded, are memorised on a magnetic disc and then worked out on a computer which will represent the image of a transversal anatomical section (with a thickness of 13 mm) of the head of the patient, in the form of an 80 x 80 matrix.

The elements of the matrix (Picture Elements) in this version have dimensions of 1.5 x 1.5 mm.

The computer will thus resolve a system of 28800 equations (equal to the total number of readings) in 6400 unknowns (equal to the total number of matrix elements). The numerical value corresponding to each element of the matrix (CT number) is proportional to the absorption coefficient of the corresponding volume of material in the section examined. Thus, the result of a tomographic examination has become an illustration of the density values of the tissues present in the section considered.

The CT numbers can be printed on paper or screened on a screen using a converter, which transforms the numerical values into various gradations of gray (white = maximum absorption and thus maximum density; black = minimum absorption) in accordance with an appropriate scale. The image recorded is kept in the form of a photograph of the image appearing on the screen. Fig. 6 shows a block diagram of the operation described.

The CT numerical scale of this first generation of instruments covers a range of 1000 units (called, by some, H units in honour of the inventor, Hounsfield[14], taking, as references, the water (zero) and, as extremes, the compact bone (+500 H) and the air (-500 H) and represented by:

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$$H = (\mu \ tissue - \mu water) \times 1000/\mu \ water$$

Fig. 7 shows the values of the absorption coefficients of some materials, obtained with an EMI scanner. From the figure, it is possible to observe that the variation in absorption of the single tissues is within a range of 4%.

If the diagnostic requirement is to examine, in particular, the soft tissues of the cranium one can proceed so that the "window" of the absorption values of the tissues (4%) covers the entire range of tones of gray. It is, of course, possible to vary the window level as desired and also the width of this window, according to the conditions and the substances to be observed[15].

In the case of the EMI, the monitor has a tone variability corresponding to eight degrees of gray.

The first generation includes (v. Table 1) in addition to the aforedescribed Mark I CT 1000 made by EMI, the first apparatuses that appeared on the market.

The first CT whole-body scanners made by Pfizer (ACTA 0100 = 0200) put on the market, and the Densitome made by CGR, do not use a water cone as a means of balance: this different technical solution does not involve inconvenience, for corrections are made to the values recorded by the detectors, which take account of the non-homogeneity of the tissular thicknesses scanned.

2nd Generation

The scanners of the 2nd generation use up to 60 detectors distributes according to a range of x-rays of limited diameter. This arrangement allows angular increments of more than one degree (from 3° to 30°) and more rapid scanning times (from 4 minutes to 10 seconds).

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The scanning method is still rotary (series of linear scans with successive angular increments), but, as the scanning is more rapid, errors in the reconstruction of the image and due to any movements on the part of the patient, are more effectively eliminated. This is therefore very important, in the case of body scanning (for example, on the thorax) where physiological movements (respiration, heart-beat etc.) can produce serious drawbacks for the precise reconstruction of the image. The latter is improved with the increase in the number of readings, making it possible to depict the image on a much larger matrix (up to 320 x 320 elements), in which the elements are of a smaller dimension (up to 0.5 x 0.5 mm). This reduction in the dimensions of the matrix also improves the resolving power of the scanner.

In the second-generation instruments it is, then, possible to obtain less thick sections (8 or even 5 mm) and vary the angle of the scanning plane by ± 20°.

Among the scanners of the second generation we may quote the new EMI models for the head (CT 1010) and for the body (CT 5000 and 5005); the Ohio Nuclear types (Delta scan 25, 50 and 50 fast) and the Pfizer model (ACTA 0200 FS),(v. Table 1) which are the models on which most clinical experimentation has been carried out and on which one can find data in literature.

3rd Generation
The so-called third-generation CT scanners use a range of x-rays which embraces the entire dimension of the object examined corresponding to a hundred detectors. The source-detector system rotates continuously through a circle of 360° and the x-ray source is pulsed. The scanning times are reduced to 5-10 seconds per stratum, increasing, even more, the sharpness of the image. This is also aided by

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the possibility of using matrixes of up to 515 x 512 elements as a consequence of the increased number of readings.

The different scanning method involves a different manner of preparing the data provided by the detectors, but following, however, the same principles described in the preceding paragraphs.

Among the firms that have used that have used the rotary system (v. Table 1) we may mention General Electric (CT/T scanner) and Varian, two American industrial giants.

2.2 Two different approaches

Actually, the three generations of CT scanners correspond to to two distinct philosophies of constructing, which co-exist, alternating in the market.

The first system, called the "translate rotate system", which corresponds to the 1st and 2nd generation scanners, derives from a beam (1st generation) or a fan (2nd generation) of x-rays which moves in parallel with, or lateral to, the body of the patient and then rotates at a certain angle before repeating the linear scan. The greater part of the scanners operating today and thus most approved for clinical use, are based on this method[7].

The alternative system, called "rotate system", widely adopted by the firms later entering the market)3rd generation) is that which uses, as the source, a fan of x-rays rotating continuously around the body of the patient. This method presents some advantages[7]: the scanning time is less, the fan of x-rays being wider, allows many more simultaneous readings and the mechanical system is simpler.

The principal problem with the rotating system, more than with the translate rota system, is associated with the detection of the x-rays, in the translate rota system, the detectors scan along the entire body and a possible error in detecting is distributed over the total image. In the rotary system, on the other hand, certain areas of the body are seen, exclusively, by specific detectors or groups of detectors. This means that the detectors should be calibrated and coupled more accurately to avoid false results.

The defenders of the rotary system assert that the problem can be overcome by processing the data properly . and constantly re-calibrating the detectors (with respect to the air density noted) before the tomographic examination.

A necessary expedient, for both systems is to reduce, as far as possible, the empty spaces between the detectors. This can allow the almost complete absorption of the photons generated by the x-ray tube, obtaining the maximum possible information on the density of the object examined, without having to increase the number of photons, which would increase the dose given to the patient.

It would also be possible to distinguish, in the technological development of the scanners, a fourth generation, differing from the third only by the different arrangement of the detectors.

These are fixed, so they do not follow, in rotation, the x-ray tube, and are arranged in large numbers in a circle (up to 600 detectors usually consisting of BGO — bismuth germanate oxide — crystals).

The static arrangement of the detector system allows the constant electronic re-calibration of the single detector in relation to the absorption value of the air; also, certain areas of the body are no longer viewed exclusively by specific detectors or groups of detectors.

From this generation of scanners we may reasonably expect an improvement in the quality of the tomographic image and lower doses of radiation because of the greater scanning speed. The instruments that use this detector system are the CT made by AS&E and the latest models made by Ohio Nuclear (Delta Scan 2005, 2010, 2020).

2.3 Theory of image reconstruction

A beam of x-rays, passing across any transversal section of the human body, is absorbed and thus more or less markedly attenuated, according to the density and atomic composition of the tissues crossed.

Describing an anatomical section with a function $f(x,y)$ of the coordinates of the plan parallel to the section itself, which represents the evolution of the density of the tissues and is correlated with the linear absorption coefficient of the tissues, it is possible, by measuring of the x-ray attenuation from different angles, to reconstruct the image of the desired section.

Defining a ray as a straight line passing through the object examined, in the case of an apparatus using the translate-rotate system, it is located by the angle θ which is formed with the axis y and the distance from the origin (v. fig. 8). Using a coordinate system (x', y') rotated with respect to the system of static coordinates of the angle θ, the distance from the origin is equal to:

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$$x' = x \cos \theta + y \sin \theta \qquad (1)$$

The integral of $f(x,y)$ along a radius called the sum ray or the projection p of the ray[15]:

$$p(x',\theta) = f(x,y) \, dy' \qquad (2)$$

A complete set of sum rays represents the projection or profile of the object a a given angle.

The value of p is obviously proportional to the attenuation of the ray:

$$p = - \ln (I/I_o) \qquad (3)$$

Where I is the intensity transmitted, measured by the detectors and I_o is the intensity of the incident ray.

Being able to obtain the values of p, calculated by measuring the ratio I/I_o, the problem of reconstructing the image becomes that of inverting Equation (2). In this way, it is possible to obtain the density function $f(x,y)$ from knowing the values of the projections.

The inversion of Equation (2) and the relative calculations are carried out with the aid of a computer which also processes the data and monitors the working of a CT scanner.

$f(x,y)$ is a bidimensional continuous function and, theoretically, infinite projections would be necessary to reconstruct the tomographic image. In practice, $f(x,y)$ is calculated in a finite number of points from a finite number of projections.

The image is reconstructed on n x n quadrate cells (pixel =
picture element) each of width d (v. fig. 9)*.

If the object mined is circular in contour, there would be
n = a/d absorption values on the principal diameter a of the
object itself. Let us assume also that there are m
projections, evenly spaced, between 0° and 180°, each of
which is constituted by n sum rays at intervals d.

To reconstruct the tomographic image various methods can be
used. Let us briefly describe some of these:

2.3.1 Back projection

This was the method used for the first reconstruction
experiments[16-18]. It is very simple and easy to
understand but it involves substantial errors in the
reconstruction of the image. This method is based on the
formula:

$$\hat{f}(x,y) = \sum_{i=1}^{m} p(x\cos\theta_i + y\sin\theta_i, \theta_i) \, \Delta \, \theta_i \qquad (4)$$

? in which θ_i is the angle of projection. θ_i is the
angular distance between the projections ($\Delta \, \theta = \pi/m$) and
the sum of the terms extends to all the m projections.

The symbol $\hat{f}$ is used in order to indicate that the result
obtained is not equivalent to the two function of density f:
in fact, the density obtained in a point is simply the sum
of all the sum rays passing through that point.

The limitation of this method lies in the fact that an
object with a very high density is reproduced on the

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reconstructed image with the characteristic star form
because its high density is attributed ndt only to its
spatial position but to all points contributing to the m sum
rays.

2.3.2 Iterative methods

In the iterative methods[16, 17, 19] (used, for example, in
the first version of the EMI scanner) we take, as a basis,
an arbitrary image of the section examined, subdivided into
n cells, to each of which is attributed an arbitrary density
value. These values are then corrected by means of
successive iterations, comparing at each passage of the
iterative process, the values of the calculated x-ray
projections with those measured by the detectors in order to
obtain the best possible agreement.

2.3.3 Analytical methods

The analytical methods are based on exact formulae for the
reconstruction of the image. Two of the most frequently
used methods will be described:

- Fouriers bidimensional reconstruction[16, 17, 20, 21]

The basis for this reconstruction is the representation of
the density function as a bidimensional Fourier integral;
$f(x,y)$, that is, is expressed as the sum of sinusoidal waves
propagated in various directions of the plane, with
amplitudes equal to the Fourier coefficients. The basis of
the reconstruction is that the Fourier coefficients of the
image are correlated with the Fourier coefficients of the
projections. In particular, the amplitudes of the waves
propagated at an angle θ are really equal to the Fourier
coefficients of the projection of the x-rays at the same

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angle.   The Fourier coefficients of the image can then
easily be obtained from those of the projections, thus
permitting the reconstruction of the image.

- Filtered back projection[18, 20]

This method is similar to the aforedescribed back projection
with the difference that the x-ray profiles are previously
modified or suitably filtered.   The modification of the
profiles is completed by using various analytical methods
permitting a more exact reconstruction of the image and not
involving the faults characteristic of the back projection.
Generally, in order to reconstruct the tomographic image the
analytical methods are preferred to the iterative methods
because of the greater speed of calculation[17].   In fact,
not just one complete analytical reconstruction is made by
the computer in the time that would be required for a single
iteration, but each single projection at a given angle can
be processed just as soon as it has been measured, without
waiting for the completion of the whole set of measurements,
as would be necessary with the iterative methods.

With the analytical methods, therefore, it is possible to
obtain a complete image of the section examined a few
seconds after the last scan has been completed.

The iterative methods, however, provide a better result in
the case where they have, at their disposition, only
incomplete data, that is a number of projections not
sufficient   to completely define the image.   This case,
however, is more frequent in radiology with radioisotopes
than in tomography;   in fact, all, or nearly all, the
scanners on the market use analytical methods for processing
data.

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2.4 Assessment of the performances of a CT scanner

The evaluation of the performances of a CT scanner comprises three principal components[22]:

1) selection of the relevant parameters to ensure satisfactory clinical results;
2) at the same time, procedures and mechanisms for measuring these parameters;
3) definition of methods for comparing the desired performances with the measured performances.

It is difficult, today, to evaluate the standard performance of a CT, in view of the recent development of this technique and the continuous technological improvement; however, it is felt that there is a requirement for standardisation whether for the method or for the units for measuring the numbers with which the absorption coefficients in CT scanners are evaluated[24].

The result given by a computerised tomogram is, as we have seen, an image obtained with various shades of gray or with various colours related to variations in the density of the tissues examined. The primary output of a CT, however is a group of numbers related to the attenuation properties of the x-rays examining the tissue and thus to the linear coefficient of attenuation μ, which, in its turn, is dependent on the density, the composition of the material and energy of the photons of the beam of x-rays used. Since the x-ray source emits photons of various energy, the numbers that are obtained are more precisely correlated with the effective linear coefficient of attenuation $\bar{\mu}$, averaged over the various energies of the photonic spectrum. With these operational conditions in mind, it is possible to select and then evaluate[22] the parameters that provide a

measurement of the performance of a CT scanner.

2.4.1. Precision

The precision of a CT scanner can be evaluated by considering the standard deviation from the mean value of the result (expressed in numerical units) of a tomogram obtained for a material of uniform density (water, for example). The standard error (noise) is calculated by dividing the standard deviation by the square root of the number of points used to calculate the same. It is evident that, with a greater spatial resolution, due to smaller dimensions of the picture element and thus to a larger number of points, there would correspond a smaller standard deviation, which would compensate for the increase in noise due to the increased resolution. On the other hand. it is by no means true that two images, one of which is obtained with a spatial image 4 times greater, but also with double the noise, will have the same diagnostic value. It is generally advisable, for measuring the precision of a CT, to choose the standard deviation over the single measurements and to consider, instead, the standard deviation of the mean only when one has to deal with identical spatial resolutions.

2.4.2 Scale of contrast

The numbers obtained with a CT scanner are arbitrarily correlated with the range of attenuation coefficients for the tissue examined. To obtain a measurement of precision in the evaluation of the attenuation coefficients of the x-rays, it is necessary to determine the conversion factor between the CT numbers and the attenuation coefficients. This is done by establishing the scale of contrast of the CT scanner, thus assessing the amount of variation in the

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x-ray attenuation that produces a reasonable difference in the CT numbers. Once the spectrum of photon energy is established, it is possible to determine the coefficients of attenuation and thus to derive their scale of contrast. For the energies used by most scanners, the range of attenuation of the tissues is adequately covered by those plastic materials which present attenuation and plexiglass. The scale of contrast can then be determined, using complete measurements, for example, on a plastic material and water; it should also be independent of the voltage applied to the x-ray tube and of the geometry of the object examined, if the scanner show linear characteristics.

The standard deviation of the attenuation coefficients (σ) is generally calculated as a percentage in respect of the coefficient of attenuation of water, by means of the formula[22]:

$$\%\sigma \ \mu_w = \sigma \ .CS \ . \ 100/\mu_w$$

in which μ_w is the mean coefficient of attenuation relative to water and relating to the measurement conditions and CS is the conversion factor relative to the scale of contrast used.

The percentage standard deviations of the coefficient of attenuation play an important part in the performances of a scanner, given that the difference in the linear attenuation coefficient of the x-rays across normal and pathological tissues is very small (of the order of 1-3%). Thus, the percentage standard deviation of the attenuation coefficient of the CT should be of the order of 1%, or less (for example 0.5%), particularly in the case of a neurological CT. This means that the scale of contrast (that is, the variation in the linear coefficient of attenuation per CT number) should

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be small enough not to compromise or limit the desired resolution of the coefficient of attenuation.

2.4.3 Linearity

A CT instrument is said to be linear if there is direct proportionality between the CT numbers and the attenuation coefficients of the tissues of the subject examined. Verification of the linearity is essential for the interpretation of a CT examination, since, on this, depends the resolution of the contrast of the tomographic image.

2.4.4 Accuracy

By accuracy we mean agreement between the values of the attenuation coefficients measured with a CT scanner and the values expected in the same conditions of measurement (voltage, filtration, atomic composition, physical density of the subject etc.). For a CT unit from which linearity is expected, the proof of a linear relationship between the CT numbers and the linear attenuation coefficient relative to the measurement conditions can, indirectly, establish the accuracy of a scanner.

2.4.5 Spatial independence

The CT numbers resulting from a tomographic examination should be independent of how the head or body of the patient is placed inside a CT instrument, whether surrounded or not by a canopy of water. Actually, in the case of a tomographic scan, the result of an examination is affected by the appreciable non-homogeneity produced by the hardening of the x-ray beam which passes through the subject examined.

When a polychromatic beam of x-rays passes through the material, it is, preferentially, the low energy photons that are absorbed so that the beam crossing through greater thicknesses becomes, proportionally, richer in high-energy photons, or more penetrating, or "hard"[?³]. The result is that the attenuation is no longer a linear function of the thickness of the material penetrated. Obviously, this produces various faults in the reconstructed image according to whether or not water is used around the subject examined. The water canopy is used so that the x-rays pass through the same gross thickness of water and tissue.

This remedy, however, does not completely eliminate the effect of hardening of the beam: it is, in fact, necessary to pre-filter the beam itself and to apply a software linearisation correction to the values recorded by the detectors.

With greater reason, it will be necessary to correct the absorption values recorded by the instruments not using a water canopy.

2.4.6 Spatial resolution and resolutive power

The resolutive power of a CT instrument (or the minimum assessable dimension) is related to the dimension of the element of the matrix (pixel) on which the image is reconstructed: it will be so much greater or so much less than the width of "pixel". This does not mean that it is not possible, from a tomogram, to recognise an object of the same dimensions as the single small cell (pixel), given that it is necessary to take account of the noise (which increases as the resolution becomes greater) and of the contrast. In fact, the possibility of detecting a small, high-contrast object will be greater than detection of the

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same object would be in the case of low contrast.

In this respect, as we have already said, in many CTs there is the possibility of using "windows" which greatly increase the contrast, while the resolutive power stated is that relative to pixel dimensions of a pixel measuring 0.75-1.5 mm.

2.4.7 Exposure

A different technical solution regarding the movement of the x-ray source naturally produces significant differences in the spatial distribution of the exposure of the patient subjected to the tomographic examination[22]. For example, if the x-ray source made up of a single beam, that produces a fan of x-rays (v. fig. 10), scans the patient with a translatory movement repeated at different angle points until it covers an arc of 180°, the distribution of the exposure will not be uniform. In fact, the exposure values will be higher for the portion of the skull directly irradiated and closer to the x-ray source. In the reverse case of an x-ray source tat moves with a purely rotational movement around the subject to be examined and completes an arc of 360°,distribution of the exposure will be more uniform and probably lower than in the previous system, especially if the source is pulsed.

The exposure, the noise, the spatial resolution are in a CT strictly related and, thus, a knowledge of this relationship is fundamental for determining the exposure required for a result of sufficient quality.

Brooks and Di Chiro[25] have shown how the standard deviation can be represented by the following equation:

$$\sigma\ (\mu)\ \propto\ (B/d^3 h D_o)^{1/2}$$

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in which B is the fraction of attenuation of the subject, d the width of pixel, h the thickness of the tomographic slice and D_o the maximum dose applied. The equation shows how even a reduction in the thickness of the "slice" increases the noise, but not so much as a reduction in the width of the "pixel". This pronounced dependence of σ on the width of pixel indicates that in some situations (for example, in order to detect liver metastases) it is preferable to use low noise and wider matrix elements (pixels) than a greater resolutive power with a very great noise.

According to McCullough et al it is probably a good thing if a CT scanner operates on three levels:

a) medium resolution (pixel width = 1.5 mm)
    low noise level (% $^\circ\mu_w$ = 0.5
    dose in patients (3-4 rads/set of scans)

b) high resolution (d = 1.0 mm)
    high noise level (%$^\circ\mu_w$ = 1.0-1.5)
    low dose in patient (1-2 rads/set of scans)

c) high resolution (d = 1.0 mm)
    low noise level (%$^\circ\mu_w$ = 0.5)
    high dose in patient (8-10 rads/set of scans)

3. CLINICAL USE OF THE CT SCANNER

3.1 Diagnostic safety

In neurological pathology, the diagnosis, as well as being based on the clinical and objective picture of the patient, is based on a large number of neuroradiological techniques. Let us sum up, in the following, the principal methods currently applied[45]:

a) Radiological examination

The opacity of the cranial enclosure constitutes an almost insurmountable obstruction to the penetration of x-rays; soft rays can not get through, hard rays do not produce any distinction between the various tissues of the encephalon, that show equal transparency. Direct x-rays, on the other hand, are useful in the diagnosis of these intracerebral tumours that show calcification (for example, the *meninges* or when associated with other methods.

b) Cerebral arteriography

A means of iodated contrast is inserted via the carotid artery, in order to make the cerebral vessels opaque. After this, one or two radiograms are made. The examination is a delicate one and reveals only those lesions that cause a change in the vascular system.

c) Pneumoencephalography

Filtered air or oxygen is injected via the lumbus; by contrast, the gaseous material shows, on a photographic plate, the subarachnoidal spaces and the cerebral ventricles. This examination makes it possible to explore the circulation of the liquor and of the ventricles, but no information is obtained as to the inner cerebral substances. It is also a potentially dangerous method.

d) Cerebral scintigraphy

This technique uses a radioactive isotope which is injected endovenously. The result of a scintograph is a map of the topographic distribution of the radiation emitted by the isotope, observed in the appropriate manner. The tracer is concentrated largely in the pathological tissues when there is an alteration in the vascular system and in the haemato-cerebral permeability; this occurs mainly in tumours. Investigation, therefore, remains ineffective in many cerebral affections and the images do not always make a distinction between the different tissues.

e) Electroencephalography (EEG)

It is the graph of the electric activity of the cerebral cortex and is obtained transcranially by means of suitable electrodes connected with an electronic system which amplifies the electric potentials of approximately one million volts. So EEG plays an important part in the examination of brain functions but can not solve all the difficulties encountered in clinical practice.

f) Echo-encephalography

This is a diagnostic technique, which consists in the recording of the ultrasonic echoes reflected by the brain and by its pathological processes. The method is based on the principle that the ultrasonic wave is reflected by the interface between two media (brain and cephalorachidian liquid or pathological process) having different densities or velocities of sound propagation. The waves reflected by the brain (or by any haematoma, tumours, etc.) are recorded on a fluorescent and photographic screen. This examination makes it possible to detect the position, the form and the magnitude of the lateral ventricles; it is also very useful in the diagnosis of acute vascular processes, trombonic occlusions, haematoma and tumours.

At present, thanks to the CAT, the diagnoses in neurological pathology are much easier, faster less harmful to the patient and less dangerous.

The results to be expected from this new method can be summed up as follows:

3.1.1 Tumoral pathology

Tumoral pathology provides one of the most valid applications of computerised axial tomography. With this technique, it is possible to pinpoint, fairly easily, any tumours, those in a central line or with ventricular expression and also the deep tumours affecting the gray nuclei or the white substance of the cerebral hemispheres. On the contrary, the neoplasma of the median cerebral fossa or of the subdural space and in the lateral direction, those of the topographic regions near the bone are more difficult to identify.

For example[26], as to their position, the tumours of the pontocerebellar angle (fitting between the petrous mass and the air of the mastoid) are diagnosed only if they are of a certain dimension or are very much vascularised.

The meningioma, especially of the acervuloma type, are easily detected because of the calcification in them.

The gliomae show only a minor density in the surrounding cerebral tissue and in them, we can recognise haemorrhagic streaks, necrotic areas and cysts of a density that is still less than that of the tumour itself.

With regard to the cerebral metastases[27], it is noted that, if they are small in dimension, they stand out by the

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oedematosous aura surrounding them, and if they are of larger dimensions, by possible endotumoral cavitation.

Failing these preliminary signs, from a diagnostic point of view, other neurological methods are more useful, for example, carotidography (provided that the metastases are sufficiently vascularised). It is emphasised that, in the case of metastases of limited dimensions, the administration of steroids may reduce the surrounding oedema and thus prevent and render difficult their identification with the CAT[27].

3.1.2 Vascular pathology

In this field, the differential diagnosis between softening and intracerebral haematoma can be made in the majority of cases since the coagulated blood is of raised density, related to the content of calcium and haemoglobin. One can distinguish a single or multiple haematic gathering and it is possible to define the oedema surrounding it. If it is a question of softening, the ischaemic zone appears as a triangular image, wedgelike, much less dense than the surrounding cerebral tissue. It is also evident that is form circumscribes the occluded vessel. As regards vascular aneurisms or malformations, the diagnosis can be made with the scanner alone if they are larger than 5 mm. In the reverse case, one must resort to angiocarotidography with means of contrast.

It is important to note that[28] the CT can diagnose the presence of an intracerebral haemorrhage even when the cerebrospinal liquid extracted by lumbar puncture shows no trace of blood.

3.1.3 Traumatic pathology

The importance of the CT is easily understood in traumatised subjects being a rapid and fundamental diagnosis as regards risk to life. It will be possible to distinguish a contusion from a haematoma and between an intra or extra cerebral gathering.

3.1.4 Degenerative pathology

With the CAT, noting the variations in size and shape of the ventricular and cisternal spaces, it is possible to diagnose cerebral atrophy, hydrocephalus and porencephaly.

Recent experience with the total-body scanner[20] has shown that this diagnositc method can be very accurate in the study of the various organisms of the human body.

It is thus possible to diagnose neoplasma, phlogistic affections and changes in the normal morphology.

The initial data indicate that this technique will assume a primary role in the study of the liver, pancreas and retroperitoneal cavity, while, in the pulmonary field, the results obtained are less decisive.

Let us analyse, briefly, the research carried out with CT on individual organs:

Liver[30,31]
The normal liver presents a homogeneous coefficient of x-ray absorption, if we exclude the areas closest to the diameter biliar region. Any intrahepatic dilatation of these areas is easily recognisable so it is possible to make a differential diagnosis between the icterus caused by biliary

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obstruction and the icterus due to other causes.

The primary and secondary neoplasma, as also the abscesses, are generally of lesser density with respect to the integral parenchyma; also, with abscesses the limits of the tumoral mass are less clearly defined. The difference in density between normal parenchyma and tumour may be later accentuated, endovenously, by the contrast. It is interesting to note that, at present, the cirrogenic evolution of a hepatic disease can not be diagnosed with the CT.

Pancreas[30,31]
The entire gland can be recognised in the majority of cases. Pancreatic neoplasmas produce, in some cases, a non-homogeneity in the gland. For example, in certain malignant tumours, in the head of the pancreas, we can see areas of low density from top to bottom; these are probably to be attributed to obstructions in the larger pancreatic duct associated with an oedematous component.

It is clear that the diagnosis will be the easier, the greater the change in the morphology of the organ.

Kidneys[24, 29, 30]
Single, benign cysts are easily recognisable even without it being necessary to inject a means of contrast endovenously and they appear rounded and with more clearly defined limits than the malignant tumours. The latter are easily diagnosed, since they alter the normal renal contour and can invade the perirenal structures given the typical invasive power. Also, their density is less than that of the normal renal tissue but not so markedly as in the case of the cystic formations: this diverse density can be even more clearly demonstrated by administering, endovenously, a means

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of contrast.

Stones in the kidney, whether those located inside the parenchyma or those displaced into the calyx, are easily visible and quickly recognised.

Retroperitoneal cavity[29, 30]
This is an area which is difficult to observe by the normal radiographic techniques, whereas it lends itself well to the use of the CT; in fact, the organs contained in the retroperitoneal cavity have a density different from that of the masses of fat surrounding the organs themselves. It is thus possible to distinguish lymphonodal tumefaction or tumoral masses and also any aneurismatic dilations of the aorta.

Notwithstanding the importance, in clinical practice, of the lung system, in view of the "filter" system of the pulmonary vascular network, especially as regards metastatic neoplasma, it is nevertheless difficult to use CT to define and diagnose affections of this type.

In fact, the obstacles opposing the practical application of the tomographic technique with regard to the lungs, are varied: first of all there are all the respiratory movements which provide sufficiently explanatory images only if the scanning times are fast enough.

For these reasons, it is not always possible to distinguish, on the basis of differing densities, normal parenchymal areas and tumoral noduli, whether benign or malignant.

An analogous assessment is carried out as regards the myocardium, the contractual movements of which are too rapid compared with the scanning times. For that reason, it is

hoped that the future development of the CT technique will involve adequate use of the apparatus either for pulmonary or for myocardiac pathology.

3.2 Comparison with other diagnostic techniques

The great diagnostic accuracy of the CT examinations (according to Baker[32], the diagnostic error in a CT examination is within 4-5%, in the cases examined, of which about half are false positive diagnoses and half false negative diagnoses) justifies the constant increase in the number of tomographic examinations. Four years of experience in the Mayo Clinic, Rochester, Minnesota, have provided data which demonstrate how the frequency of some types of normal neurodiagnostic examinations undoubtedly decreased after the advent of the CAT.

The pneumoencephalography, because of the high risk to the patient, showed the greatest reduction: in fact, the frequency of this examination tends towards zero.

Echo-encephalography and cerebral scintigraphy providing information less specific than that from the CAT have been drastically reduced: the number of monthly examinations has been practically halved.

The frequency of angiographic examinations of the cerebral vessels has been partly reduced, but not so much as the method previously mentioned. It is, in fact, evident that the vascularisation of given areas and cerebral masses, although being explorable with the CAT, finds, in this method, its precise application. Angiocarotidography is replaced by the CAT practically only for images of pre-senile dementia, aspecific convulsive disorders and, in some cases, brain damage.

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On the other hand, the only neurological examination which has not shown any decrease has been the electrocephalogram (EEG).

This was predictable in so far as the EEG represents the one source of information on the electrophysiological of the cerebral cortex. It, therefore, constitutes a source of essential information not obtainable by any other techniques.

The data provided so far, refer, as mentioned above, to the Mayo Clinic. Analogous results are, however, obtainable in other hospitals, as we see from the conspicuous literature on the subject.

Interesting, in this respect, are the experiences accumulated over two years of work on the CAT at the regional Hospital "Umberto I", in Ancona[21]. The results are not appreciably different from those of other particular users.

A comparative study of the CAT total body scanner and other diagnostic techniques relating to pathological effects involving other portions of the human body apart from the skull, can be carried out, strictly speaking, only in the future. However, we can look forward to increased clinical experimentation, such as to provide a real and in-depth comparison of the various methods.

4. DOSIMETRY

4.1   Review of dosimetric data

4.1.1   Head scanner   EMI CT 1000

The data reported by Perry and Bridges[34] describe a description of skin exposure by the prototype of the EMI (1st generation) for a single complete scan.

The measurements of the exposure were done with the help of an ionisation chamber placed at different points of a water model, 130 mm in diameter.

Table 2[3] shows the exposure values obtained at two different voltages of the x-ray tube and for different position of the ionisation chamber.   We may recall that the x-ray tube completes successive linear scans, describing an arc of 180° (from 0° to 180°).

According to Hounsfield[3], the area of irradiated skin being restricted by a thin strip around the head of the patient, the effect of superimposition of two adjacent sections can be ignored.   Hounsfield, however, concludes that the dose on the skin does not increase with an increase in the sections examined and that the maximum exposure (1.9R to 120 KVp) is approximately equivalent to a conventional x ray examination of the head.

Perry and Bridges, quoted in the previous section, as well as given, as an estimate of the dose on the gonads during each head scan, a value of much less than 0.1 mrad, completed a detailed study for the characterisation of the field of radiation around the CT scanner.   For this, they used, as the detector instruments, an EKCO type N 555

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dosimeter. Rather than determining the exposures at every point during a complete scan, the measurements were carried out with the x-ray tube in fixed positions (x-ray beam placed horizontally and pointed in a direction opposite the scale of contrast or else in an intermediate position as to linear scanning movement). Only the head of the patient was simulated with a water model and the measurements were carried out without the rest of the patient's body.

The isodosic curves, in the case of two different voltages of the x-ray tube, are represented in fig. 11, where the exposures are expressed in mR/hour. Dividing these values by 10, we obtain, approximately, the exposures relating to a complete scan. The same authors measured the effect on the radiation field of losses in the x-ray tube and of different radiation (v. fig. 12). An actual estimate of the exposure at every point in the site in which the CT apparatus is placed may be obtained by taking an average of the exposure values recorded during a 180° rotation of the x-ray tube. McCullough et al, too, report[35] ambient dosimetric values relating to the EMI CT 1000, measured with a Victorian 444 dosimeter. The conclusions are, that the exposures are less than 3 mR/hour at a distance of one metre from the scanner, while in an area close to the high-voltage terminals of the x-ray tube, the exposure values measured – still at a distance of one metre from the scanner – increase to 12 mR/hour (at 120 KVp) or 25 mR/hour (at 140 KVp).

4.1.2 Head scanner EMI CT 1010

This type of neurolgical scanner belongs to the 2nd generation and therefore uses a wider x-ray beam than the prototype and a greater number of detectors (16 crystals of NaI, 8 per tomographic section). The source-detector system carries out the complete scan, corresponding to an

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arc of 180°, in one minute, with angular increments of 3°. The complete scan also provides, at the same time, two adjacent tomographic sections. The image is reconstructed on a matrix of 320 x 320 with pixel dimensions of 0.75 x 0.75 mm.

McCullough et al[35] report the data relative to the EMI CT 1010, obtained by using thermoluminescent dosimeters inserted in an Alderson humanoid model. The values of the doses absorbed, represented in fig. 13, refer to a single scan (2 adjacent tomographic sections).

Bhave et al[36] have provided the results relating to measurements of diffused radiation in the case of neurological scans carried out on children aged from 4 days to 12 years. The measurements were obtained with thermoluminescent dosimeters (TLD) placed at eye level, and involved the thyroid and the gonads. The results are given in Table 3 and refer to a typical study of the cranium, consisting of 4 tomographic scans (8 tomographic sections) with 120 KVp and with a collimator of 8 mm. The same table, by way of comparison shows dose values produced by diffuse radiation in the case of the usual radiological examinations.

The same authors also carried out measurements on the corpse of a day-old baby, in order to determine the incident skin dose received by scanning (1 scan corresponds to a 225° rotation of the x-ray tube and produces two adjacent tomographic sections). The results show how the average skin dose per scan is 1.3 rad (with variations of between 0.5 and 2.5 rad) using an 8 mm collimator and a voltage of 120 KVp. Measurements obtained at 140 KVp then indicated that the doses are around 5% higher than those obtained at 120 KVp: when using a collimator from 15 mm the dose

increased by 30%. On the other hand, the dose measured[36] in the case of a series of radiographs on the head on children weighing 10 kg, was 300 mrad, while in a scintigraphic examination of the brain the integral dose is approximately 250 mrad.

4.1.3. EMI CT 5000

This is a scanner model for the whole body and belongs to the 2nd generation in which 30 detectors are used (NaI crystals) per tomographic section, arranged on an arc of 10°. The movement of the source-detectors system, in successive linear scans is repeated at angular intervals of 10°. Also, it is possible to make a selection between two scanning speeds (20 and 70 seconds), in the case of slower scans, the noise is reduced by a factor of 2, while the dose in the patient increases by about 4 times[35]. The x-ray tube is identical with that used in the CT 1010 with the possibility of operating at 100, 120 and 140 KVp.

The matrix on which the image is reconstructed has the form of 320 x 320 with variable pixel dimensions (0.75 x 0.75, 1 x 1, 1.25 x 1.25 mm) according to the diameter of the subject examined.

A scan produces the image of a single tomographic section unlike the previous EMI instruments which provide two simultaneous ones, with a maximum thickness of 13 mm.

The level of noise ($\%^{\sigma}\mu_w$) calculated by McCullough et al[35] varies from 0.63 to 1.8, according to the dimensions of the subject examined. The range of contrast is relative to the variation of the 23% of the linear coefficient of attenuation per CT number. The spatial resolution calculated is 1.5 mm for a diameter of about 25 cm of the

patient's body and 2 mm for a diameter of 33 cm.

The dose absorbed by the patient was measured, still by the same authors, with thermoluminescent dosimeters arranged in an Alderson humanoid model, in various scanning conditions (v. fig. 14).

Preliminary measurements made by Sagel et al[30] also indicate that a tomographic study of the abdomen (with 140 KVp, 28 mA, 18 seconds per scan) carried out with 5 scans (5 adjacent tomographic sections) comprises a maximum dose of about 3 rads skin dose, while the internal dose absorbed varies from 1 to 3 rads.

4.1.4 Ohio Nuclear Delta 25 Head scanner

The data provided by Weinstein et al[37] refer to the first model of the Ohio Nuclear (2nd generation of scanners).

This instrument operates with voltage and current, at the x-ray tube, of 130 KV and 30 mA; the source-detectors system (the detectors used are BGO crystals, BGO = bismuth germanate oxide) completes an arc of 196° with linear scan every 7°. A scan produces, simultaneously, two adjacent tomographic sections, and the image is reconstructed on a matrix of 256 x 256 elements, each with dimensions of 1 x 1 mm.

The noise calculated ($\%^{\sigma}\mu_w$) is about 0.6. The scanning times are 185 and 130 seconds.

The dose measurements per scans with a speed of 130 sec, were made with thermoluminescent dosimeters placed on the surface and inside a water dummy.

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The values of doses reported in the article quoted per
scanning speed of 185 sec, were obtained by doubling those
obtained with a lower scanning speed.

The results are given in fig, 15 for various positions of
the dosimeter for a variable number of scans and for 3
different thicknesses of tomographic section.

4.1.5. Ohio Nuclear Delta Scan 50 (whole body) brain scanner

The Delta Scan 50 model, belonging to the 2nd generation,
has the following characteristics:

·   the detectors (CaF_2) are 3 for each tomographic section
(one scan produces two adjacent sections);

-   the source-detectors movement completes an arc of 180°
with linear scans every 3°;

-   the matrix on which the image is reconstructed has the
form of 256 x 256 with pixel dimensions of 0.75 x 0.75 to
1.75 x 1.75 mm;

-- the values of %·µ· are between 0.51 and 0.77 and the
resolutive power calculated is 1.75-2.00 mm in the case of
brain scans completed in 2 minutes;

-- the values of %·µ· between 1.42 and 1.63 calculated
resolutive power of 2.00 mm in the case of body scans
completed in 2.5 minutes[30].

Measurements of doses were carried out by Bassano et al[34]
with TLD-100 (3 x 3 x 0.9 mm) in an Alderson mode, with a
range of uncertainty of ± 20% (v. fig. 16). The authors
state that the measurements underestimate by a factor of

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approximately 1.5   5. which depends on the collimation   of
the   beam.   the   dose   received   during   a   tomographic
examination because of the overlapping due to the   execution
of a moderate number of scans in the course of the   complete
tomographic examination.

The isodose curves in an abdominal scan were reconstructed
from 5 or 6 measurements completed in 15 various   positions
of   the   abdomen (v. fig. 17).   The dose in the   gonads   was
measured by using a Rando model an electrometer model (35020
Keithley) combined with a diagnostic camera of 15 m^3.   The
uncertainty of the measurement is of the order of ± 15%   (v.
fig. 18 and Table 4).

4.1.6   Pfizer ACTA 0100

This   instrument   which is the first CT for the   whole   body
that   appeared   on   the   market,   has   the   following
characteristics:

   the x-ray tube operates at 90 KV/10 mA 120 KV/14 mA.

-   the detectors (CaF_2 crystals) are 2 in number (1 for each
tomographic section. given that a scan produces two adjacent
tomographic sections);

-    the source-detector movement covers an arc of 180°   with
linear scans every degree or every 2°.

-   it is possible to use two forms of matrix with 160 x   160
or 320 x 320 elements, each of which has dimensions of 1.5 x
1.5 mm;

-   the thickness of section is 7.5 mm;

it is possible to obtain images in colour (with a range of 16 colours);

in the case of brain scans $\%^{\circ}\mu_{\star}$ = 0.80, calculated resolutive power = 1.75 mm and scanning time 4.5 minutes;

in the case of a body scan $\%^{\circ}\mu_{\star}$ = 1.33, calculated resolutive power = 2.00 mm and scanning time 5.5 minutes[35].

The maximum absorption dose according to McCullough et al[35], obtained with TLD dosimeters placed in an Alderson model. is approximately 2.1 rad for a single scan, while, according to Ledley[5], this value is approximately 1 rad.

4.1.7 Instruments using the rotary method

The lack of experimental data, in literature, relating to this type of apparatus forces us to supply dose values obtained by the manufacturing firms.

For example, Ohio Nuclear states, for the 4th generation model Delta Scan 2020, (scanning time 2 seconds), that the dose values absorbed in the case of a tomographic examination of the head are:

1.4 — 1.7 rad (single scan), 1.9 — 2.6 (multiple scan consisting of 8 sections).

and in the case of a tomographic examination of the body:

1.3 — 1.6 rad (single scan), 1.9 — 2.4 (8 sections).

General Electric , on the other hand, gives a maximum dose value of around 1.2 rad for the model Fast Scan CT/T total body scanner (scanning time 4.8 seconds). This scanner (3rd generation) uses a pulsed x-ray source and the dose values stated refer to a complete scan (rotation of x-ray tube = 360°) carried out with 576 pulses, each lasting 3.3 ms.

4.2 Analysis of dosimetric data

From a first analysis of the dosimetric data provided in literature there appears a considerable lack of homogeneity.

the values of dose absorbed by the patient during a tomographic examination were measured in various operational conditions and thus make it difficult to get an accurate comparison between the results reported by the individual authors. This being so, we have tried to sum up, in Table 5, the maximum dose values absorbed by the patient during a tomographic examination of the head.

Assuming that it is necessary to distinguish between dose values measured by an accurate technique and estimated, approximate values, it is emphasised that the considerable dependence of the dosimetric value on the conditions in which the CT is used, makes it necessary, first of all, to analyse the parameters that influence the determination of the dose absorbed by the patient:

4.2.1 Scanning method

As we have already said, the scanning method, as is logical to expect, influences the distribution of exposure in the patient. In the rotary system this is uniform throughout the whole of the tomographic section examined, while this is

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not so in the case of the rotary system[35] (v. figs. 11,
12, 13 and tab. 2.1). Unfortunately, the data available in
literature, previously reported, refer only to CT scanners
tested between 1972 and the present day. These instruments
all belong to the 1st and 2nd generation and their
functioning is based on the roto-translatory method. In
this respect, it is underlined that while the 1st generation
instruments use a single x-ray beam, those of the 2ns
generation use a greater diameter of x-ray beam in relation
to the greater number of detectors used. This may mean an
increase in the levels of dose absorbed by the patient, even
if the scanning times are shorter. In fact, comparing, in
Table 5, the maximum values of dose administered in the case
of a neurological examination given with the EMI CT 1000
(prototype), the EMI CT 1010 (series model, 1st generation)
and the EMI CT 5000 (2nd generation) it can be noted how,
although the scanning method increases, the dose does not
decrease.

Similar reasoning may be advanced in the case of the dose
given to the patient in the course of a tomographic
examination with instruments of the 3rd and 4th generation,
which use x-ray beams with an even larger aperture so to
cover the diameter of the object examined. However, it can
be reasonably expected that these instruments can provide
lower doses, not only in relation to their greater scanning
speed but also because of the possibility of using a pulsed
x-ray source. However, although as the literature is
lacking in information relative to these new appliances, it
is clear that the maximum dose values given by the
manufacturing firms (v. tab. 5) have been subject to
successive experimental checks.

4.2.2 X-ray tube used

The energy applied by the x-ray tubes to the tissues is a function of the working conditions of the x-ray tube. Generally, in the commercial instruments, voltages of 120 - 140 KVolt are used, with anode currents of approximately 30 mA.

The possibility of using various voltages means great variations in the dose absorbed by the patient, as can easily be seen from the data reported in Table 5.

4.2.3 Alignment of x-ray beam

A fundamental condition for the use of a CT appliance, as for all radiogenic sources, is that the x-ray beam must be properly aligned so as to avoid irradiating body zones other than those to be examined and to avoid overlapping of the fields of radiation.

It is also known that the perfect functioning of an x-ray apparatus reduces the risk of radiation to which the patient and the operator are exposed[38].

4.2.4 Scanning speed and quality of the image

The great variability in the scanning times (from 5 seconds to 5 minutes) naturally produces considerable variations in the dose absorbed by the patient. Often, a CT has various scanning speeds, so one selects the most appropriate speed in relation to the required resolution of the tomographic image and to the risk for the patient, thus working with parameters which influence the quality of the image so as to provide the maximum information obtainable with the least dose given to the patient[38].

As already demonstrated in the previous paragraphs, the quantity of information obtainable from a tomographic examination is linked to the number of photons emitted by the x ray source associated with the detector system. For the latter, the empty spaces between the detectors, in a CT scanner, must be reduced to a minimum so that the number of photons obtained will be the highest possible.

It is worth repeating that the close relationship existing between absorbed dose and quality of image must induce one to evaluate, with the aim of protecting the patient, the performance of a CT scanner, not only on the basis of levels of dose applied, but also in relation to the quality of the tomographic image produced, in order to avoid useless repeated examinations.

4.2.5 Number of scans, thickness of sections and effects of the superimposition of radiation fields

Generally, a tomographic examination consists of more than one scan; for example, for a complete examination of the skull a number of scans producing 6 or 8 tomographic sections may be sufficient.

More scans, however, may cause overlapping of radiation fields with a consequent increase in the dose to the patient. This effect is related to the thickness of the tomographic sections and to the alignment of the x-ray beam. According to some authors[3, 34] well-aligned x-ray beams should not produce appreciable overlapping of two adjacent sections even if, in the portion of the subject examined and opposite the irradiated direction, the exposure may have a value effectively higher because of the "widening of the x-ray beam". The same authors conclude that the skin dose should not appreciably increase when the number of sections

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examined increases.

According to Bassano et al[38], on the other hand, one
cannot ignore the superimposition effect: in fact, these
authors affirm that the measurements completed in a section
submitted to a single scan give lower values of dose
received in the course of a complete tomographic examination
by a factor of 1.5 - 5, depending on the alignment of the
x-ray beam. The authors thus recommend recording of the
dose values for a single tomographic section during the
execution of the complete tomographic examination.

This recommendation is supported by the other experimental
results reported in Table 5 and is fundamental for the
correct evaluation of the risk-benefit ratio relating to a
tomographic examination.

In this respect, it is also fundamental not to forget the
importance of correct use of the CT instrumentation which
should be operated by expert and qualified personnel, in
order to avoid operational errors which could greatly
increase the risk to the patient[40].

5. CONCLUSIONS

The ever-increasing use of the CT scanner in radiodiagnostic
practice raises, essentially, two kinds of problems: the
first is connected with the effective clincal use of the CT
in relation to the risk-benefit ratio associated with a
tomographic examination.

As we have had occasion to explain, the costs of the
exercise are necessarily associated with the number of
examinations that can be carried out in a year: in fact, in

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the greater number of cases, a CT appliance is supplied, as it were, "on hire". The experience gained in the Ospedale Civile, Ancona, indicates that, having available a sufficiently well-organised hospital organisation and using the CT full time, it is possible to reduce the cost per examination to an acceptable level.

It can be reasonably affirmed that this new radiodiagnostic technique contributes, in some cases, to the formulation of an exact clinical diagnosis. The functional aim of organisation and management is to avoid a tomographic examination when it is not actually necessary; this either because it is almost better to avoid useless irradiation of the patient or because a large number of requests could prevent the execution of those tomograms essential for the actual life of the patient, for example, a tomogram of a head injury. An analysis of the cost-benefit ratio of a CT examination is also, as is obvious, related to the logical distribution of CT units throughout the national or local area. In Italy, it is the private clinics which have been predominant in the technological development represented by CT instrumentation and it should be the prerogative of the public health organisation. In this respect, it must be clear, that the possibility of carrying out a tomographic examination can not be interpreted as an incentive to demand the examination itself. As with any clinical or radiological investigation it is necessary to use, and not abuse it, as such examinations can involve more or less risk to the patient. In fact, even if the evaluation of the risk-benefit ratio linked with a CT examination should be the prerogative of the doctor, it is well to remember that the dose given during tomographic scans can not be described as "low". As is possible to observe from Table 5 previously reported, the maximum dose per examination seems to be around 2 - 10 rad, with a dose to the gonads subject

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to considerable variations depending on the type of appliance used and on the manner in which the latter is operated.

The continual technological evolution, to which instrumentation of this type is subject, leads us to hope for a definite improvement in the tomographic images accompanied by a reduction in the dose given to the patient. Many researchers are moving in this direction and, in particular, have completed studies tending to maximise the information provided by x-rays from the tissues, thus improving the efficiency of the detection system[44]. At present, industrial trends are towards improvement in the quality of the image, not only by reducing the scanning times but by the use of microbeams of x-rays, so as to take full advantage of the information provided by the individual photons[44]. Another important result refers to the possibility of synchronising the tomographic scan with given physiological phenomena, such as the respiration and heartbeat.

There is finally, a problem, perhaps the most important one to be solved: that of the legislation relating to the introduction of the CAT in the national health organisations. The requirement for legislation, like the requirement for the standardisation of the method, has already been felt in other countries which either have already set limits or have tried to plan, nationally or locally, for the acquirement of a CT. It is thus to be hoped that this problem will be faced and resolved also in Italy, before the non-public health organisations compete for the prestige of determining the development and distribution of an important diagnostic instrument which should, instead, be at the service of the whole population.

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Captions of figures and tables

Fig. 1   Operational   principle   of   the   conventional
         tomograph[45].   The   x-ray   tube   completes   a
         scanning arch with its rotation centre on Plane A.
         The   photographic   film,   on   the   other   hand,
         completes   a   counter-movement.   While   the
         anatomical   structures positioned on Plane A   give
         rise to images of the relatively definite contour,
         those   positioned   on   various   planes   produce
         out-of-focus images.

Fig. 2   Operational   principle   of   the   transverse   axial
         tomography[45].   The x-ray tube is fused,   while
         the patient and the film rotate through an arc   of
         360°.   The photograph plate shows,   relatively
         sharply, only the anatomical structures positioned
         on Plane A (perpendicular to the longitudinal axis
         of the patient) while those belonging to different
         planes   are fogged because of the movement of   the
         patient and of the film.

Fig. 3   Operational   principle   of   computerised   axial
         tomography.

Fig. 4   Movement   of   the source-detectors system   in   1st
         generation CT instruments.

Fig. 5   Illustration of the sequence of linear scans.

Fig. 6   Block diagram of the functioning of an EMI Scanner
         CT 1000.

Fig. 7   Scale of absorption coefficients of the   organic
           materials as a percentage of the water (on   the
           left).
           CT numerical scale (on the right).

Fig. 8   System of x,y coordinates in which is   described
           the "density function" f(x,y).   Each ray is
           defined by the angle θ formed with the axis y   and
           by its distance x' from the origin.

Fig. 9   Example of reconstruction of a circular image   on
           a square matrix with n x n elements, each of
           dimensions d x d.

Fig. 10   Illustration of the various systems of   scanning
           used by three generations of CT scanners:
           a) roto-translatory method: single   beam of
               x-rays, angle increases of 1° for a total
               rotation arc of 180°.
           b) roto-translatory method: fan of x-rays,angle
               increase of N° (greater than 1°) for a total
               rotation arc of 180°.
           c) rotary method: continuous rotation through
               360°, fan of x-rays.

Fig. 11   Field of radiation around a Head Scanner   EMI   CT
           1000.   The exposure values   are   expressed   in
           MR/hour.   The characteristic voltage/current   of
           the x-ray tube is 120 KVp/32 mA.   the diagram was
           taken   form the British J. Radiol. 46, p. 1048
           (ref. 34).

Fig. 12   As in fig. 11 with the difference that the
           characteristic, voltage/current is 140 KVp/27 mA.
           the diagram was taken from the British J. Radiol.
           46, p. 1049 (ref. 34).

Fig. 13   Dose absorbed, in rad, for scanning in accordance
           with McCullough et al[35] in an EMI scanner CT
           1010 (120 KVp/33 mA).

Fig. 14   Dose absorbed in rad during a tomographic brain
           examination with an EMI scanner CT 5000. The dose
           values were obtained by McCullough et al[35] for 5
           different positions, in a section of the patient's
           head.
           Notes for table: 120 = 120 KVp; 140 = 140 KVp;
           N = scanning time of 70 s; V = scanning time of
           20 s; 1 = one tomographic section; 3 = three
           adjacent tomographic sections; 5 = five adjacent
           tomographic sections.

Fig. 15   Dose absorbed, in rad, during a tomographic
           examination of the brain using an Ohio Nuclear
           Delta 25, according to Weinstein et al[37].
           Notes for table: 5, 8, 13 mm = thickness of
           tomographic section, N = scanning time of 185 s;
           V = scanning time of 130 s; 2, 8, 12, 20 = number
           of adjacent tomographic sections.

Fig. 16   Dose absorbed, in rad, during a tomographic
           examination of the brain, using an Ohio Nuclear
           Delta 50, in accordance with Bassano et al[38].

Fig. 17   Isodose   curves,   in   rad,   corresponding   to   a
           tomographic   examination   of   the   abdomen   with   an
           Ohio Nuclear Delta 50, in accordance with   Bassano
           et al.

Fig. 18   Dose   applied   to gonads in mrad   per   tomographic
           section   as   a   function   of   the   scanning
           position[38],   for   an   Ohio   Nuclear   Delta   50
           scanner.

                              TABLES

Tab. 1   Characteristics   of   the   CT   instruments   on   the
           market (from Phys. Med. Biol. 21 n.5, p. 728).

Tab. 2   Exposure   values corresponding to a complete   scan
           with   an   EMI   scanner   CT   1000,   according   to
           Hounsfield[3].

Tab. 3   Dose   values,   in rad, due to   diffused   radiation
           during various radiological examinations

Tab. 5   Table recapitulating dose values from   tomographic
           examinations of the brain.

Photo 1   Facsimile   of result of a tomographic   examination
           of   the   brain, obtained with the ACTA   Scanner   CT
           0200.

Photo 2   Facsimile   of result of a tomographic   examination
           of   the abdomen obtained with the ACTA Scanner   CT
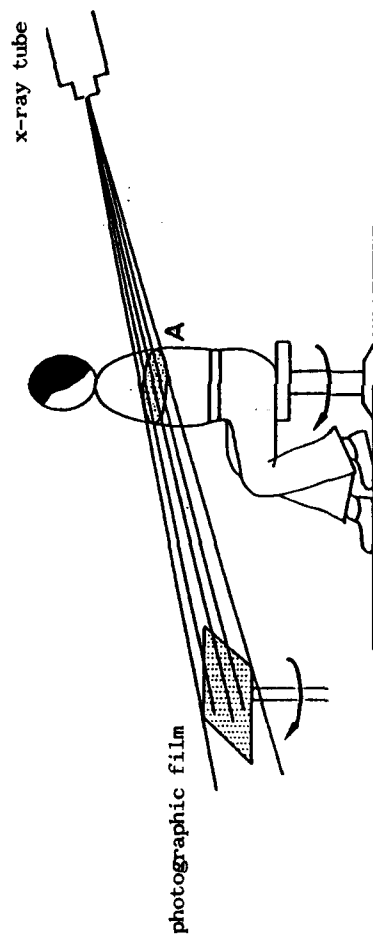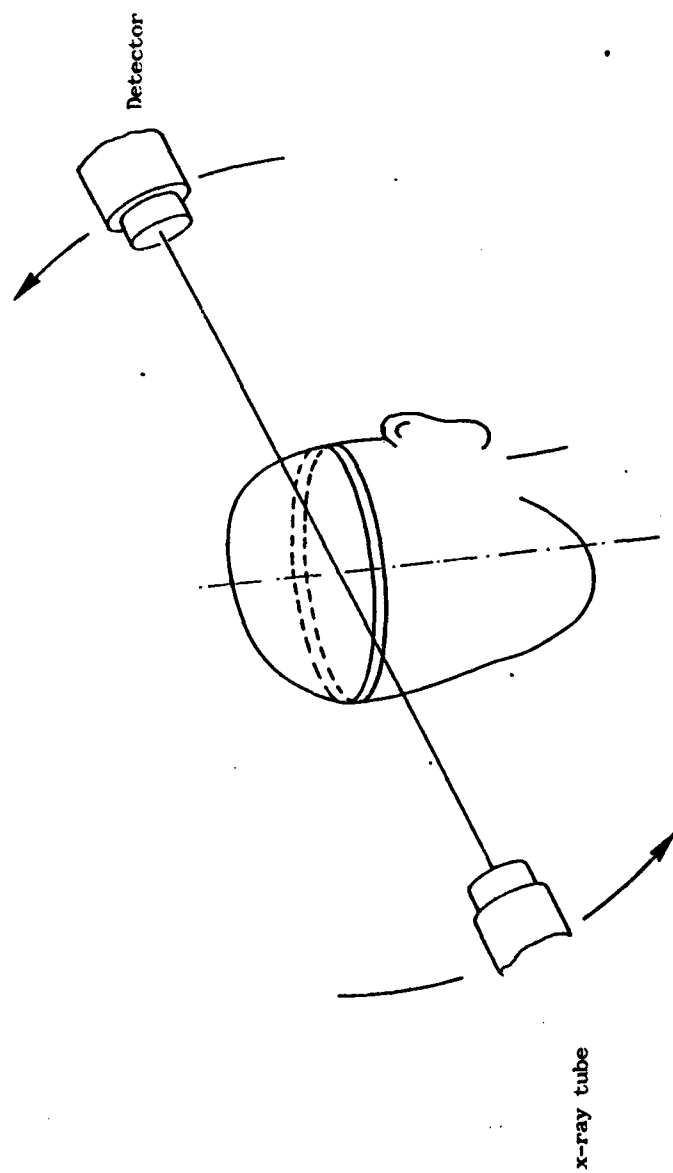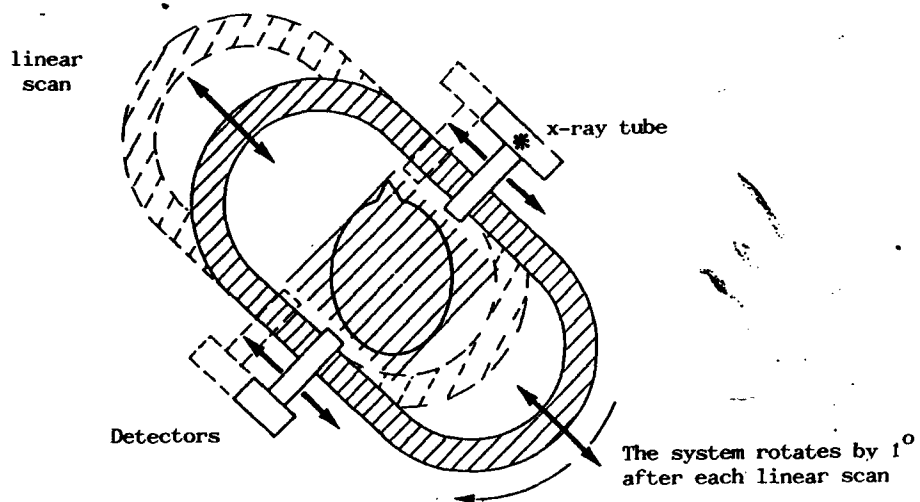   0200 FS.
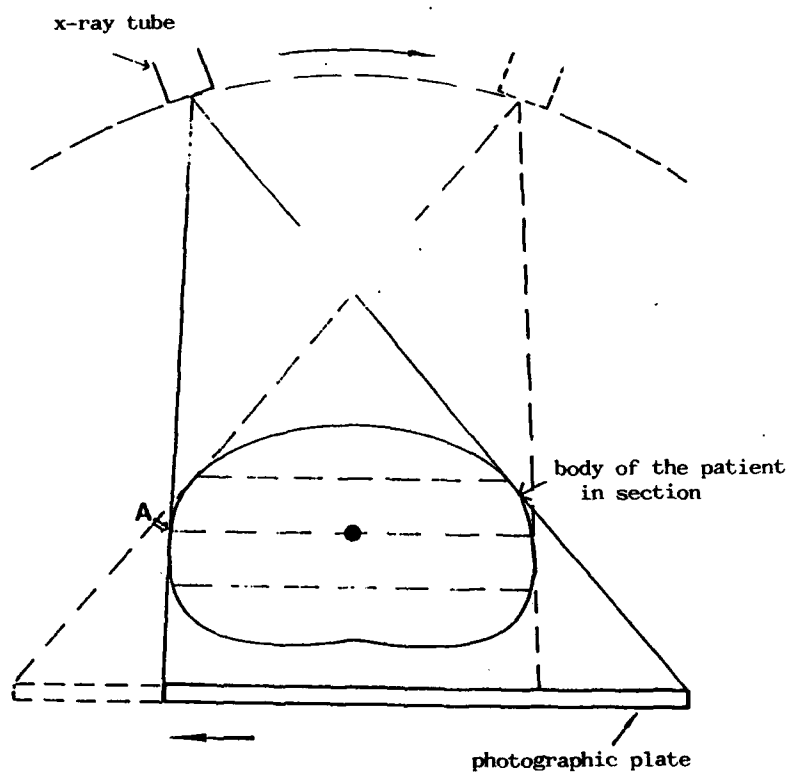
x-ray tube

body of the patient
in section

A

photographic plate

Fig.1

x-ray tube

photographic film

A

Fig. 2

Detector

x-ray tube

Fig. 3

linear
scan

x-ray tube

Detectors

The system rotates by 1°
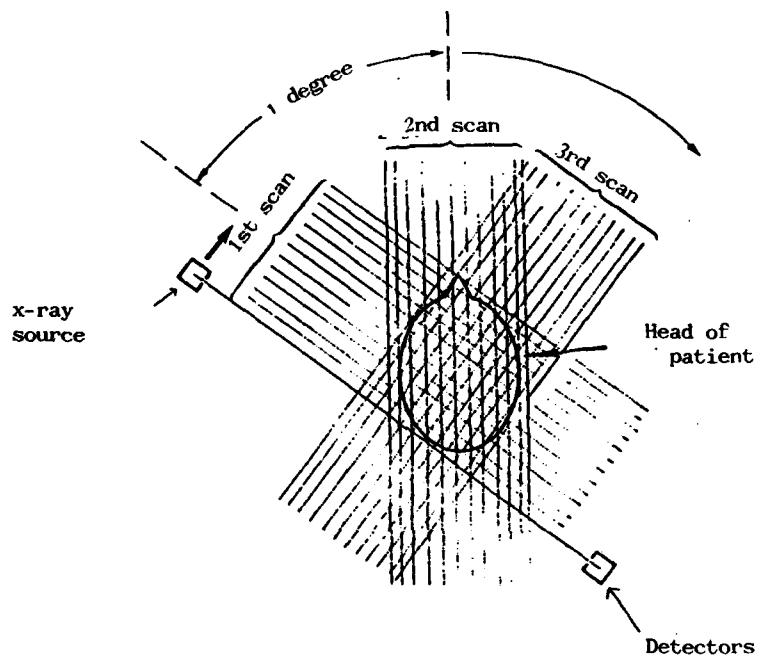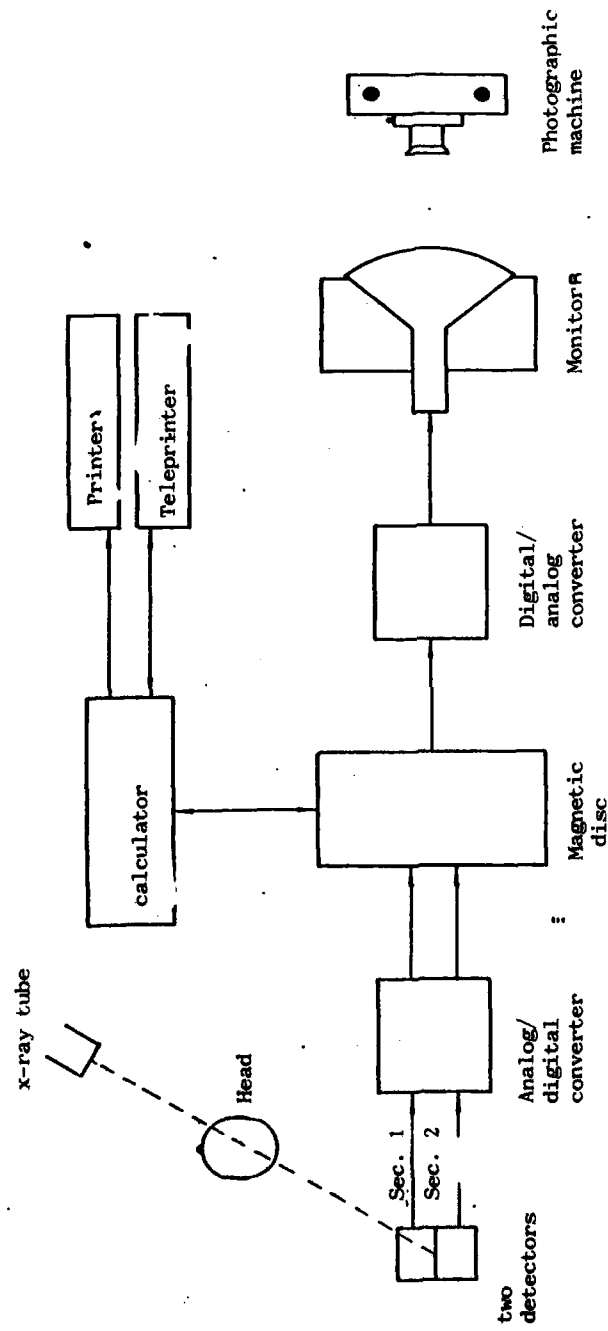after each linear scan

Fig. 4

x-ray
source

1 degree

2nd scan

1st scan

3rd scan

Head of
patient

Detectors

Fig 5

Fig. 6

Fig. 7

Fig.8

Fig. 9

a)

b)

c)

Fig. 10

one metre

X-ray
control
unit

tube

X-ray
beam

couch

Fig. 11

Fig. 12

movement of
x-ray tube

1.5
2,5   1.0   0.5
1.5
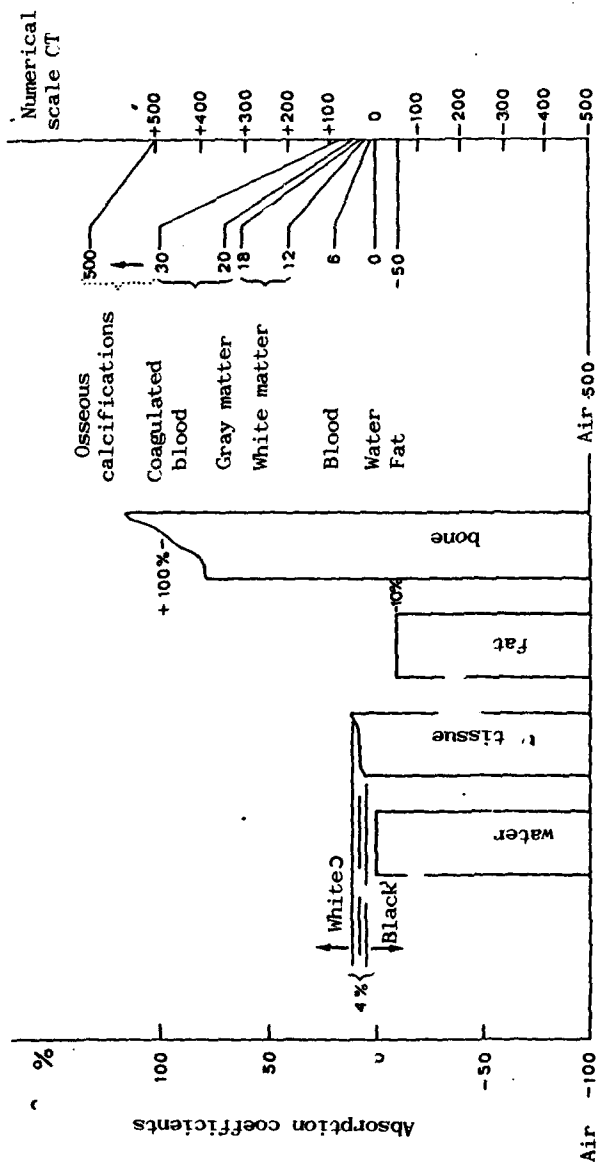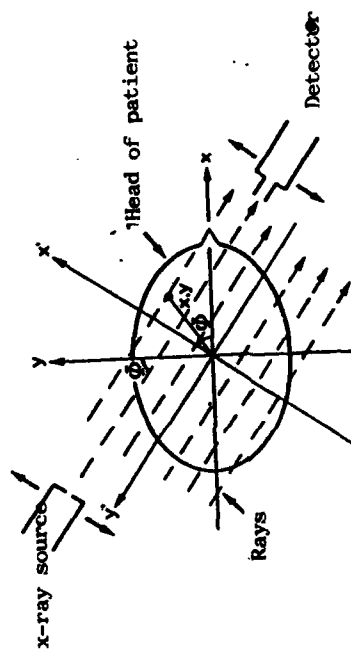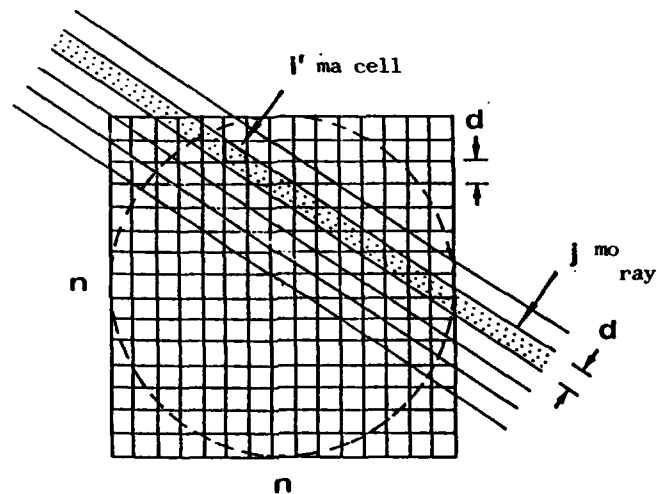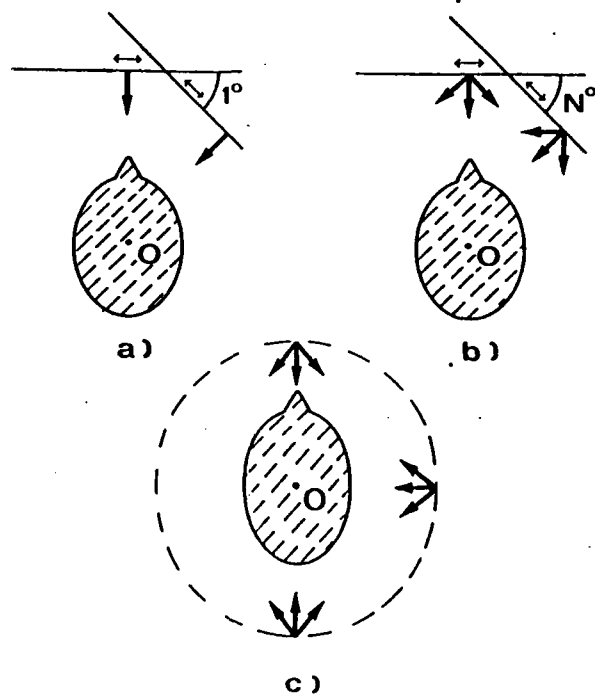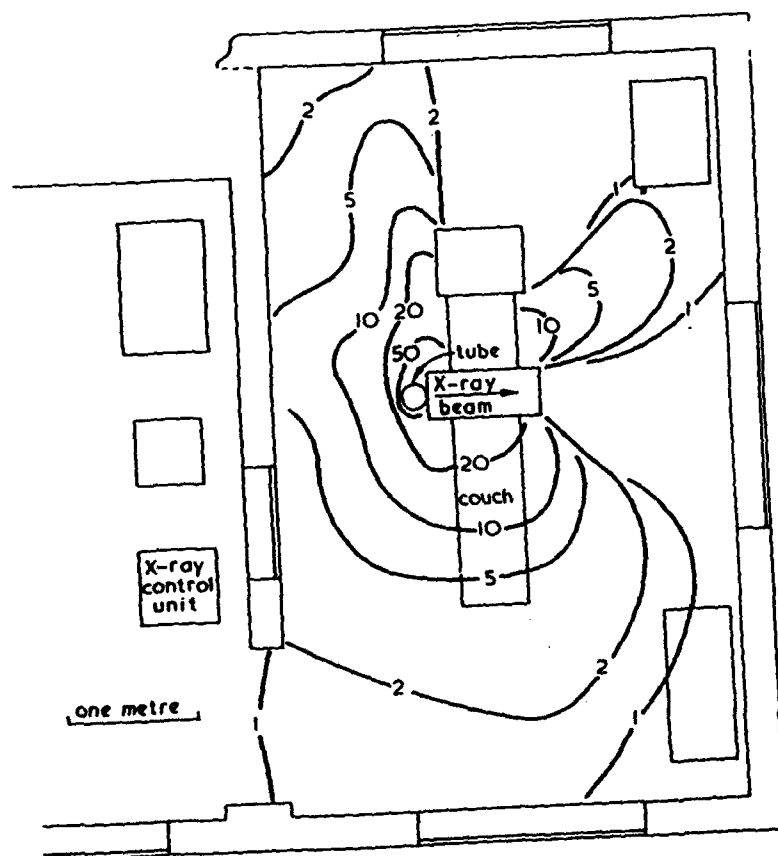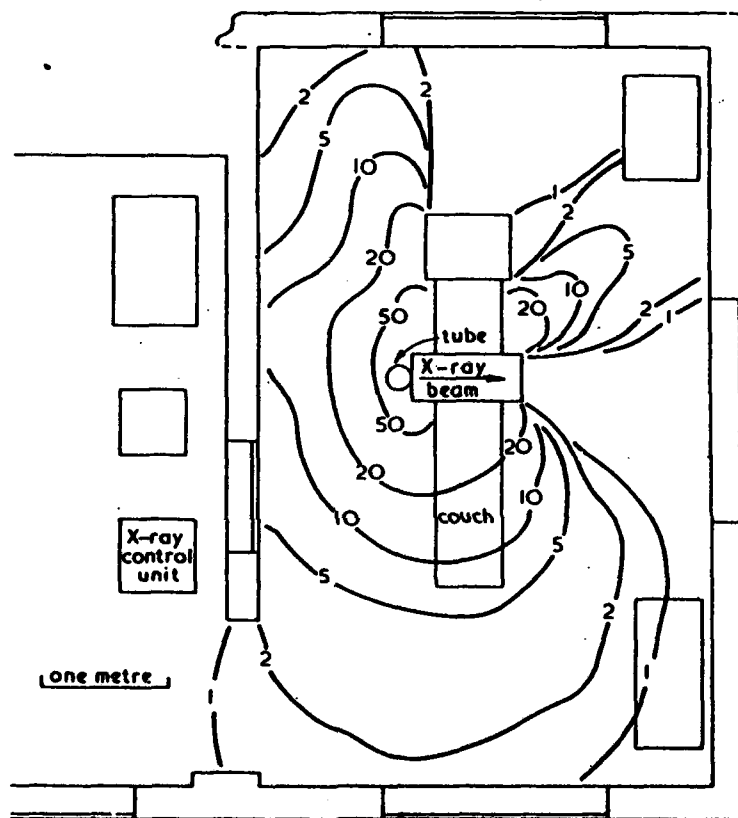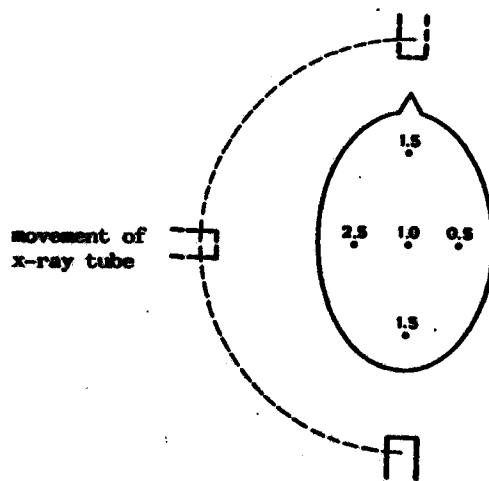
Fig. 13
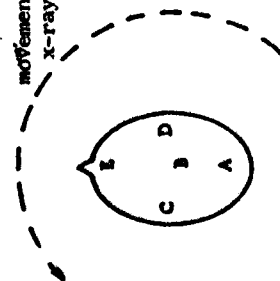
Dose absorbed, in RAD

position / characteristic parameters	A	B	C	D	E
120/N/1	1.3	2.7	4.0	7.0	6.4
120/N/3	2.6	5.3	5.9	11.4	12.4
120/N/5	2.7	6.4	6.9	14.2	13.6
120/V/5	1.5	1.3	2.0	4.7	4.3
140/V/5	1.8	2.0	2.6	5.1	5.4

movement of x-ray tube

Fig. 14

Dose absorbed in RAD Ohio-Nuclear Delta '25 Head Scanner

Position / characteristic parameters	A	B	C/D	E
N/2	11.6	-	-	2.2
V/2	5.8	-	-	1.1
N/8	12.0	5.0	8.0	4.0
V/8	5.9	2.5	4.0	2.0
N/2	10.6	-	-	2.0
V/2	5.3	-	-	1.0
N/12	15	5.6	8.6	4.8
V/12	7.7	2.8	4.3	2.4
N/2	10.6	-	-	1.4
V/2	5.3	-	-	0.7
N/2u	16.0	6.4	10.6	5.6
V/20	7.8	3.2	5.3	2.8

13 mm, 8 mm, 5 mm
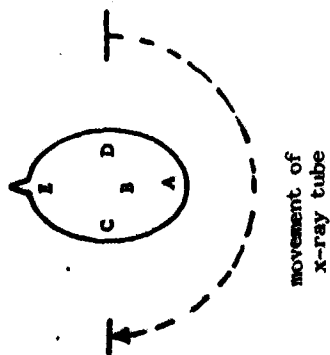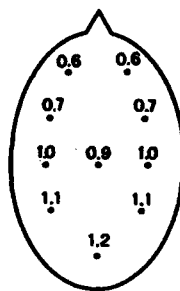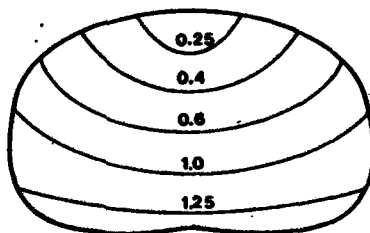

movement of x-ray tube

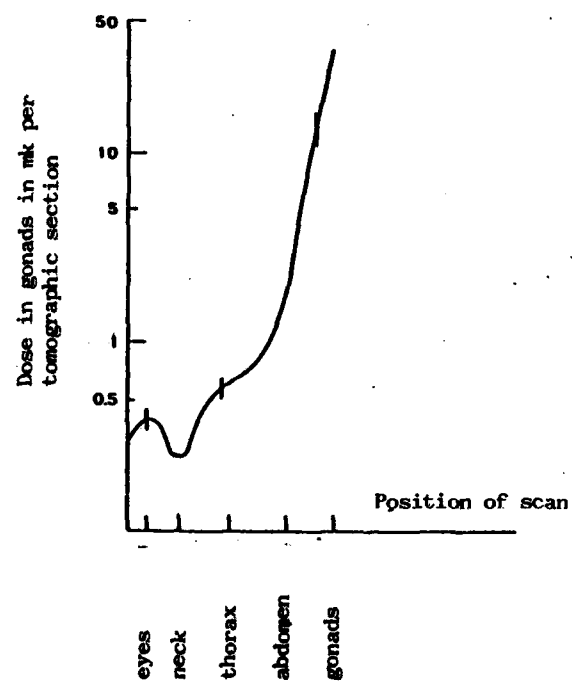Fig.15

Fig. 16

Fig. 17

Fig. 18

TABLE 1

Bitta costruttrice - manufacturing firm
Modello - model
Tipo di applicazione - type of application
Revelatori per sezione tomografica - detectors per tomographic section
Esistenza di un cappuccio d'acqua - presence of a cone of water
Movemento angolare - angular movement
Formato della matrice - form of matrix
Dimensioni di cella (mm) - dimensions of cell (mm)
Tempo di scansione - scanning time

Testa - head
a passi di - in steps of
corpo - body
Torace - thorax
Generazione - generation
Rotazione continua - continuous rotation

* The scan produces 2 sections simultaneously: the total
  number of detectors is thus double.

TABLE 2

Exposure values corresponding to a complete scan with an EMI
CT 1000.

Posizione della camera a ionizzazione - position of
ionisation chamber
Posizione equivalente della testa del paziente - equivalent
position of patient's head

Esposizione in Roentgen per una scansime completa - x-ray
exposure for a complete scan
posteriore, laterale, anteriore - posterior, lateral,
anterior

TABLE 3

Dose values from diffused radiation

Occhi - eyes   Tiroide - thyroid   Gonadi - gonads
Soggetti esaminati - subjects examined
Referimente - references
Angiografia cerebrale - cerebral angiography
Rx al cranio - x-ray exam of skull
(4 lastre) - 4 plates
bambino - child
bambino di 12 ans - 12 year old child
bambini - children
adulti - adults
casi - cases
nostra mesura - our measurement
preliminare - preliminary

TABLE 4

Dose in gonads from diffuse radiation (mrad) with Ohio
Nuclear Delta 50[35]

Sezione del corpo scansionata - section of body scanned
Numero di sezioni di spessore 13 mm - number of sections of
13 mm thickness

Numero di sezioni di spessore 13 mm - number of sections of
13 mm thickness
Dose ai testicoli - dose in testicles
Dose stimata alle ovaii - estimated dose in ovaries
cervello - brain
fegato - liver
addome - abdomen

This dose is essentially due to direct radiation.

TABLE 5

Dose values per tomographic examination of the brain

Marca e tipo - trade name and type
Tempo di scansione - scanning time
Spessore di sezione - thickness of section
Numero di sezioni - number of sections
Dose max in rad - max. dose in rad
Dosimetro utilizzato - dosimeter used
Referimenti - references
Fantoccio - model
Dose alle gonadi - dose in gonads
Errore sulla dose - error in dose
Minuti - minutes
per 8 sezione - for 8 minutes
camera di ionizzazione - ionisation chamber
ad acqua - to water
diametro - diameter
ditta costruttrice - manufacturer

Tabella 1

Ditta Costruttrice	Modello	Tipo di applicazione	Rivelatori per sezione tomografica	Esistenza di un cappuccio d'acqua	Movimento angolare	Formato della matrice	Dimensioni di cella (mm)	Tempo di scansione
1 Generazione								
EMI	Mark I, CT1000	Testa	1 NaI*	Si	180/225° a passi di 3	160	1-5	4-5 min
Hitachi	CT-H250	Testa	1 NaI*	Si	180° a passi di 1	256	1	4 min
CGR	Densitome	Testa	1 prop.*	No	180° a passi di 1	128	2	4 min
Pfizer	ACTA 0100	Corpo	1 CaF2*	No	180° a passi di 1 e 2	160/320	1-5	4-5 min
2 Generazione								
General Electric	CT/N (II)	Testa	3 NaI*	No	180° a passi di 3	160	1-5	2 min
Siemens	Siretom II	Testa	4 CaF2*	No	180° a passi di 1-35	256	1	1-3 min
Ohio Nuclear	Δ Scan 25	Testa	7 BGO*	No	196° a passi di 7	256	1	1/3 min
EMI	CT1010	Testa	8 NaI*	No	180/225° a passi di 3	320	0-75	1/4-5 min
Ohio Nuclear	Δ Scan 50	Corpo	3 CaF2*	No	180° a passi di 3	256	0.75-1-75	2-5 min
Ohio Nuclear	Δ Scan 50 Fast	Corpo	12 BGO*	No	180° a passi di 12	256	1/1-7	18 s
Syntex	60	Corpo	12 NaI	Opt.	180° a passi di 12	256	1/1-5	1 min
EMI	CT5000,5005	Corpo	30 NaI	No	180° a passi di 10	320	0.75/1/1.25	20 min
Pfizer	ACTA 0200FS	Corpo	30 CaF2	No	180/280° a passi di 20	160/256/320	1/1.5	21 s
Philips	Tomoscan	Corpo	30 BGO	No	180/225° a passi di 10	256	1/1.6/2	27 s
Elscint	Scannex	Corpo	60 BGO	No	180° a passi di 30	256/512	0.5/2	10 s
3 Generazione								
Artronix	1110	Testa	128 Xe	Si	360° rotazione continua	256	1	9 s
General Electric	XT/M	Torace	111 Xe	Si	360° rotazione continua	128	1-5	10 s
Picker	Synerview	Corpo	60 CaF2	No	720° rotazione continua	240	1/2	10 s
Searle	Photrax	Corpo	252 Xe	No	360° rotazione continua	256	0.5/1/2	5/10/20 s
Mass. Gen. Hosp.	CTC	Corpo	256 Xe	No	360° rotazione continua	320	0.8/1.6	5 s
Varian		Corpo	300 Xe Kr	No	360° rotazione continua	256	1-9	6 s
General Electric	CT/T	Corpo	320 Xe	No	360° rotazione continua	320	1-3	5 s
Artronix	1120	Corpo	512 Xe	No	360° rotazione continua	512	1	5 s
Am. Sci. & Eng.		Corpo	600 BGO	No	495° rotazione continua	512	0.5/1	5/10/20 s

* La scansione produce 2 sezioni contemporaneamente: quindi il numero totale di rivelatori è doppio.

Tabella 2- Valori di esposizione corrispondenti ad una scansione completa compiuta con EMI CT1000

Posizione della camera a ionizzazione	Posizione equivalente della testa del paziente	Esposizione in Roentgen per una scansione completa	
		120 KV/32 mA	140 KV/27 mA
0°	posteriore	1.2	1.6
90°	laterale dx	1.9	2.3
180°	anteriore	1.2	1.5
270°	laterale sx	0.6	0.8

Tabella 3 - Valori di Dose dovuta a radiazione diffusa

	Occhi	Tiroide	Gonadi	Soggetti esaminati	Riferimenti
EMI scanner CT 1010	0.850	0.310	0.030	bambini di 10 Kg	(36)
Angiografia cerebrale	12.5 (0.5-35.5)	-	0.030 in 8 casi	16 bambini	(41)
			0.0 in 84 casi	76 adulti	
Angiografia Carotidea	17.0 (37 esposizioni)	-	-	-	(42)
Rx al cranio (4 lastre)	-	-	0.75	bambini di 7.5 Kg	(43)
CT Sireton SIEMENS	-	-	11 mR	bambino di 12 anni	nostra misura preliminare

Tabella 4- Dose alle gonadi dovuta a radiazione diffusa (m rad) Ohio Nuclear Delta 50 [58]

Sezione del corpo scansionata	Numero di sezioni di spessore 113 mm	Dose ai testicoli	Dose stimata alle ovaie
Cervello	8	~ 1.5	~ 2
Fegato	10	~ 4	~ 6
Addome	20	~ 60	100 - 1000 *

* Questa dose è dovuta essenzialmente a irraggiamento diretto.

Tabella 5 - Valori di dose per esame tomografico cerebrale

Marca e tipo	KV/mA	Tempo di scansione	Spessore di sezione mm	Numero di sezioni	Dose max in rad	Dosimetro utilizzato	Fantoccio	Riferimenti	Dose alle gonadi in rad	Errore sulla dose
EMI CT 1000	130/32 140/27	4,5 minuti	13	2	1,0 2,3	camera a ionizzazione	ad acqua diametro 130 mm	34	0,1	
EMI CT 1010	120/33	1 minuti	8	2	2,5	TLD	Alderson	35	30	
PFIZER ACTA 0100	120/15	4,5 minuti	7,5	2	2,1 5,8	TLD	Alderson	35		
Ohio Nuclear Δ 25	130/40	2 minuti 10 sec	13 8 5	8 2	5,9 5,3	TLD	ad acqua diametro 20 cm	37		
EMI CT 5000	120/32 140/27	70 sec 20 sec	10	12 2 20 1 3 5 5 5	7,7 5,3 7,8 7,0 12,4 14,2 4,7 6,1	TLD	Alderson	35		
Ohio Nuclear Δ 50	120/30	2 minuti	13	2	1,2	TLD	Alderson	38	1,5-2 per 8 sezioni	errore dose ± 20%
Ohio Nuclear Δ2020	130/40 130/200	2 sec	7	1 8	1,4 1,9			Ditta costruttrice		
GE CT/T	120/600	4,8 sec		1 8 1	1,7 2,6 1,2			Ditta costruttrice		

Foto 1

Foto 2